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AVERAGE CHEMICAL COMPOSITIONS OF IGNEOUS-ROCK TYPES.

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Presented December 8, 1909; Received December 4, 1909.

Contents.

Introduction: Purpose of the Paper 211
Method of Calculation 213
Sources of Information 214
Average Specific Gravities of Certain Types 235
Some Applications 235

Introduction: Purpose of the Paper.

The study of the igneous rocks has hitherto largely consisted in an analysis of their mineralogical and chemical composition, with the special intent to produce a satisfactory nomenclature and classification of the rocks as they occur throughout the world. This systematic petrography, though still pursued by a great number of workers, is now rivaled in interest and excelled in importance by its own offshoot, petrogeny. The science of the origin and history of the igneous rocks is reacting on the more purely descriptive subject, and at present petrologists are feeling their way toward a genetic classification of this great series of rock-types. Meantime, the much more numerous class of workers engaged on the problems of economic and general geology, of geochemistry and cosmogony, are raising highly important questions which belong to the field of petrogenesis. The problems thus raised are as fundamental as they are complex and difficult. For many of their solutions recourse must be had to the more modern geological reports and maps. With ever increasing skill and accuracy the distribution and relations of the rocks composing the earth's crust are being recorded by government officers and by geologists working in private capacity. For some thirty years past, as at present, the great body of geologists have mapped and described the igneous rocks in terms of what may be called the German system of nomenclature and definition. In particular, Rosenbusch's monumental treatises on the

eruptive rocks have been, for a generation, the usual guide to the many authors who have described their findings among the igneous terranes of the world.

In view of these facts it is clear that a student in petrology who wishes to use the maps and memoirs should have a good conception of the rock-types recognized by Rosenbusch and by his hundreds of disciples among the field-geologists. It is true that in some details the usages of master and followers as regards names and classification have varied, but in a broad way Rosenbusch's definitions of the principal families and species of massive rocks have been used for maps and reports in all regions where modern work on igneous geology has been done. Just as the general sequence of the stratified rocks as first described in England, France, and Germany has been found to be closely paralleled in the rest of Europe and in the other continents, so the system of igneous rocks as at first developed from material largely collected in Europe has been nearly sufficient for the mapping of those rocks elsewhere. In the field as in the library the geologist soon learns that there is a persistent recurrence of types in the larger divisions of the earth's surface. The usefulness and objective character of Rosenbusch's classification are, therefore, proved by its adaptability in all the continents and islands.

Rosenbusch and his followers recognize some latitude of variation in the composition of each rock-type. The variation is both mineralogical and chemical, two rock specimens referred to a type showing differences in the proportions of the chemical elements found by analysis of the two rocks. In fact, no two analyses of granite, andesite, or any other one type have ever given precisely the same proportions of the dozen or more oxides which regularly make up an igneous rock. It is obvious that the student of map and memoir should, for many problems, have at hand the actual figures showing the most typical chemical composition of the rock-types to which his study is directed. In numerous cases an analysis of a single specimen is not so useful as that which could be made from a thorough mixture of specimens of the same rock-variety from all places on the globe where that variety occurs.

For obvious reasons such ideal analyses have never been made. In their stead the writer believes that the investigator of petrogenic and other world-problems may well use the averages calculated from the many excellent chemical analyses of rocks made since Rosenbusch's system of naming and classification has been in general use. It may, indeed, be argued that such averages would more nearly represent the chemistry of Rosenbusch's types than any of the respective single

analysis which he has published in his treatise. These averages would be chemical "center-points" in his system of classification as *actually applied* to the terranes of the world.

So far as the writer is aware, the preparation of these averages has not hitherto been attempted to such an extent as to cover the chief families and species of igneous rocks. An approximation to the desired results is offered in the following tables.

The work of computing the averages has been lessened very greatly by the publication of Osann's "Beiträge zur chemischen Petrographie" (2nd part, Stuttgart, 1905). This remarkable book contains, in convenient arrangement, the statement of most of the eruptive-rock analyses (over 2400 in number) published in the interval between 1883 and 1901. The period of seventeen years lies within that during which systematic petrography has been dominated by Rosenbusch's names and definitions. In general, the number of analyses for each rock-species is so large that their average would be but slightly modified by the inclusion of the analyses made since 1900. In many cases, therefore, the extended labor required to search out from the literature the additional analyses, has not been considered necessary for the preparation of useful averages. For other averages it was necessary to include analyses published since 1900. The sources of such information are indicated below. Fortunately for the purpose, nearly the entire period since 1884 has seen the application of more or less refined methods of analysis; so that errors of observation for the leading oxides are relatively small.

Method of Calculation.

The method of computation used is essentially like that employed by Washington and Clarke in their respective calculations of the "average composition" of all igneous rocks. In general, only the twelve more important oxides (including MnO) are recognized in the following tables. Distinctly "inferior" analyses were not considered. In each case the average was computed according to the actual numbers of determinations made by the analysts. Table I. shows these numbers for the respective rock-types, each column being headed by a key-number which corresponds with the named types of Table II. For some of the rocks BaO and SrO were computed. Their sum appears in the averages for CaO, as indicated in the tables. Similarly CO_2 and Cr_2O_3 were sometimes averaged and entered with H_2O and Fe_2O_3 respectively. As expected from the method employed, the average totals nearly always ran well over one hundred per cent. All

averages were reduced to 100.00 per cent and entered in Table II. Each average analysis was then recalculated to 100.00 per cent after H_2O (and CO_2) had been subtracted. The results are also given in Table II., in which plutonics and corresponding effusives are grouped together. Magmatic relationships are often less obscured if these volatile oxides, which may be wholly or in part of exotic nature, are excluded. Finally, in order to facilitate reference to the tables, an index to the different rock-types was prepared and may be found below Table II.

It will be observed that certain rock-types have been omitted from the tables. The large class of "aschistic" dike-rocks is not represented because of their chemical similarity to the corresponding plutonic species. Other named varieties are omitted since their analyses are too few to give useful averages. In a few cases the mineralogical and chemical variations within each variety are so great that it has not seemed advisable to regard their averages as worthy of entry. Many other subordinate varieties of rock, though given special names, are chemically almost identical with the more important types entered in the tables and therefore have been excluded.

Sources of Information.

The immediate sources of the analytical statements used in the computations are as follows: —

1. Beiträge zur chemischen Petrographie, zweiter Teil, by A. Osann. Stuttgart, 1905.
2. Chemical Analyses of Igneous Rocks published from 1884 to 1900, by H. S. Washington. Prof. Paper, No. 14, U. S. Geological Survey, 1903.
3. Elemente der Gesteinslehre, 2nd edition, by H. Rosenbusch. Stuttgart, 1901.
4. Lehrbuch der Petrographie, 2nd edition, by F. Zirkel. Leipzig, 1893.
5. Studien über die Granite von Schweden, by P. J. Holmquist. Bull. Geol. Institution, University of Upsala, Vol. 7, 1906, p. 76.
6. Some Lava Flows of the Western Slope of the Sierra Nevada, California, by F. L. Ransome. Amer. Jour. Science, Vol. 5, 1898, p. 355.
7. Matériaux pour la Minéralogie de Madagascar. Nouv. Archives du Muséum, (4), Vol. 5, Paris, 1903.
8. Geology of the Yellowstone National Park, by A. Hague and others. Petrography by J. P. Iddings. Monograph No. 32, Part 2, U. S. Geological Survey, 1899.

9. Analyses of Rocks from the Laboratory of the United States Geological Survey, 1880 to 1903, by F. W. Clarke. Bulletin 228 of the Survey, 1904.

10. Geological and Petrographical Studies of the Sudbury Nickel District, by T. L. Walker, Quart. Jour. Geol. Soc., Vol. 53, 1897, p. 40.

11. Petrography and Geology of the Igneous Rocks of the Highwood Mountains, Montana, by L. V. Pirsson. Bull. 237, U. S. Geological Survey, 1905.

12. Geology of the North American Cordillera at the Forty-ninth Parallel, by R. A. Daly (forthcoming; analyses by M. F. Connor and M. Dittrich used in calculating some averages).

The sources of the analyses used in each average are indicated by the authors' names at the head of the corresponding columns in Table II.

TABLE I.

SHOWING THE NUMBER OF SEPARATE DETERMINATIONS USED IN COMPUTING THE AVERAGE QUANTITY OF EACH OXIDE IN EACH ROCK-TYPE.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SiO_2	47	114	184	236	64	24	40	50	7	5	8	23	50	48	7	13
TiO_2	22	74	60	87	40	10	30	20	5	4	5	14	35	26	6	5
Al_2O_3	47	114	180	232	63	23	40	49	7	5	8	23	49	48	7	13
Fe_2O_3	35	101	118	158	61	22	39	32	4	5	3	15	43	38	7	10
FeO	35	101	118	158	42	6	36	32	4	5	3	14	43	38	6	10
MnO	24	86	64	93	32	4	28	20	4	5	5	14	38	34	1	6
MgO	47	114	184	236	63	24	39	49	6	5	8	22	50	48	7	13
CaO	47	114	184	236	64	24	40	49	6	5	8	22	50	48	6	13
Na_2O	47	108	182	234	63	24	39	49	6	5	8	22	50	48	7	13
K_2O	47	108	182	234	63	24	39	49	6	5	8	21	50	48	7	13
H_2O	38	40	41	41	17	15	17	39	7	3	8	21	41	44	7	10
P_2O_5	15	34	73	81	27	4	23	17	3	3	..	7	34	25	4	4
BaO	8	..	35	35	..	..	..	..	..	..	..	..	..	..	..	..
SrO	5	..	21	21	..	..	..	..	..	..	..	..	..	..	..	..

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
SiO_2	3	7	12	10	10	3	3	43	25	4	8	12	30	20	89	70
TiO_2	..	..	10	10	4	..	3	30	16	..	3	12	15	16	71	57
Al_2O_3	3	7	12	10	10	3	3	43	25	4	8	12	30	20	89	70
Fe_2O_3	3	7	12	10	6	3	3	30	18	2	2	12	24	18	86	69
FeO	2		12	10	6	3	2	30	18	2	2	12	24	18	86	69
MnO	..	..	10	10	4	3	2	30	15	1	3	12	14	11	66	53
MgO	3	7	12	10	10	3	3	41	25	4	8	12	30	20	89	70
CaO	3	7	12	10	10	3	3	43	25	4	8	12	30	20	89	70
Na_2O	3	7	12	10	10	3	3	43	25	4	8	12	30	20	85	67
K_2O	3	7	12	10	10	3	3	43	25	4	8	12	30	20	85	67
H_2O	3	7	9	10	10	3	1	26	23	4	6	12	30	17	47	36
P_2O_5	1	..	12	10	4	..	3	14	15	..	1	12	15	15	71	57

TABLE I.— *Continued.*

	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
SiO_2	87	33	20	24	10	7	41	198	161	20	17	11	9	24	17	5
TiO_2	51	16	13	13	9	6	26	132	113	13	6	5	8	16	10	4
Al_2O_3	87	33	20	24	10	6	41	197	160	20	17	11	9	24	17	4
Fe_2O_3	71	25	18	18	10	7	36	174	146	18	14	5	9	21	15	5
FeO	71	25	18	18	10	7	36	173	146	18	14	5	8	21	15	5
MnO	44	16	14	8	6	6	28	108	96	13	6	2	4	15	13	4
MgO	87	33	20	24	10	7	40	197	160	20	17	11	9	24	16	5
CaO	87	33	20	24	10	7	41	198	161	20	17	11	9	24	17	5
Na_2O	84	32	20	22	10	7	40	190	154	20	16	11	9	24	16	5
K_2O	84	32	20	22	10	7	39	190	154	20	16	11	9	23	16	5
H_2O	57	5	18	24	10	6	17	55	27	16	1	5	2	12	5	4
P_2O_5	47	14	13	11	9	6	27	135	116	14	6	4	9	16	11	4

	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64
SiO_2	2	12	4	4	3	4	3	4	49	3	11	4	7	6	6	6
TiO_2	2	4	1	4	3	..	..	2	27	..	11	2	3	3	2	6
Al_2O_3	2	12	4	4	3	4	2	4	49	3	11	4	7	6	6	6
Fe_2O_3	2	10	4	4	3	1	2	4	40	3	10	2	2	5	6	6
FeO	2	10	4	4	3	1	3	4	40	3	10	4	2	5	6	6
MnO	2	3	4	4	3	1	1	3	32	..	6	..	..	..	4	4
MgO	2	12	4	4	3	4	3	4	47	3	11	4	7	6	6	6
CaO	2	12	4	4	3	4	1	4	49	3	11	4	7	6	6	6
Na_2O	2	12	3	2	3	..	1	4	31	3	11	4	7	6	6	6
K_2O	2	12	2	1	3	..	..	4	31	3	11	4	7	6	6	6
H_2O	2	7	4	4	3	4	3	3	47	3	10	2	7	4	6	6
P_2O_5	2	1	1	4	3	..	1	2	25	3	11	2	2	2	2	6

TABLE I.— *Continued.*

	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81
SiO_2	24	20	4	20	16	4	1	2	7	7	5	9	26	3	10	4	10
TiO_2	8	14	4	4	11	3	1	2	2	6	5	3	23	3	10	4	9
Al_2O_3	24	20	4	20	16	4	1	2	7	7	5	9	26	3	10	4	10
Fe_2O_3	22	19	3	19	15	4	1	2	4	5	5	3	25	3	10	4	10
FeO	22	19	3	19	15	4	1	2	4	5	5	3	25	3	10	4	10
MnO	14	7	1	13	5	2	1	2	1	4	5	4	15	3	10	1	10
MgO	24	20	4	20	16	4	1	2	7	7	5	9	26	3	10	4	10
CaO	24	20	4	20	16	4	1	2	7	7	5	9	26	3	10	4	10
Na_2O	24	20	4	20	16	4	1	2	7	7	5	9	26	3	10	4	10
K_2O	24	20	4	20	16	4	1	2	7	7	5	9	26	3	10	4	10
H_2O	9	18	3	6	15	3	1	2	3	4	4	5	25	3	10	4	10
P_2O_5	19	9	3	16	8	1	1	2	5	2	4	6	23	3	10	4	9

	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98
SiO_2	11	4	8	5	2	6	15	5	5	8	15	10	20	4	15	16	6
TiO_2	11	4	8	5	2	6	9	2	3	7	9	8	16	4	10	12	5
Al_2O_3	11	4	8	5	2	6	15	5	5	8	15	10	19	4	15	16	6
Fe_2O_3	11	4	8	5	2	6	11	2	4	8	10	8	16	4	10	14	5
FeO	11	4	8	5	2	6	10	2	3	8	9	8	16	4	10	14	5
MnO	11	4	8	5	2	..	8	1	4	8	9	7	17	1	8	9	2
MgO	11	4	8	5	2	6	15	4	5	8	15	10	20	4	15	16	6
CaO	11	4	8	5	2	6	15	5	5	8	15	10	20	4	15	16	6
Na_2O	11	4	8	5	2	6	15	5	5	8	15	10	20	4	15	15	5
K_2O	11	4	8	5	2	6	15	5	5	8	15	10	20	4	15	15	5
H_2O	6	4	8	5	2	6	11	2	3	7	10	10	19	4	10	16	3
P_2O_5	8	4	8	5	2	5	7	..	..	7	5	7	18	4	6	11	3

TABLE II.

SHOWING THE AVERAGE COMPOSITIONS CALCULATED FOR THE PRINCIPAL IGNEOUS-ROCK TYPES.

GROUP I.

	PLUTONICS.				EFFUSIVES.			
	1	2	3	4	5	6	7	8
	Pre-Cambrian Granites, including 16 Analyses of Swedish Types (Osann).	Pre-Cambrian Granites of Sweden (Holmquist).	Granites younger than the Pre-Cambrian (Osann and Clarke).	Granite of all Periods (Osann and Clarke).	Liparite, including 40 Rhyolites (Osann).	Liparites, as named by authors (Osann).	Rhyolites, as named by authors (Osann).	Quartz Porphyry (Osann).
No. of Analyses.	47	114	184	236	64	24	40	50
SiO_2	71.06	69.81	69.73	69.92	72.60	72.90	72.62	72.36
TiO_2	.48	.54	.34	.39	.30	.48	.25	.33
Al_2O_3	14.10	13.76	14.98	14.78	13.88	14.18	13.77	14.17
Fe_2O_3	1.46	2.17	1.62	1.62	1.43	1.65	1.29	1.55
FeO	1.63	1.87	1.66	1.67	.82	.31	.90	1.01
MnO	.18	.26	.11	.13	.12	.13	.12	.09
MgO	.59	.84	1.08	.97	.38	.40	.38	.52
CaO	1.97 [1]	2.20	2.20 [2]	2.15 [3]	1.32	1.13	1.43	1.38
Na_2O	3.24	3.17	3.28	3.28	3.54	3.54	3.55	2.85
K_2O	4.50	4.38	3.95	4.07	4.03	3.94	4.09	4.56
H_2O	.69	.74	.78	.78	1.52	1.33	1.53	1.09
P_2O_5	.10	.26	.27	.24	.06	.01	.07	.09
Calculated as Water-free.								
SiO_2	71.56	70.33	70.28	70.47	73.72	73.89	73.75	73.16
TiO_2	.48	.54	.34	.39	.30	.49	.25	.33
Al_2O_3	14.20	13.86	15.10	14.90	14.10	14.37	13.99	14.33
Fe_2O_3	1.47	2.19	1.63	1.63	1.45	1.67	1.31	1.57
FeO	1.65	1.89	1.67	1.68	.83	.31	.91	1.02
MnO	.18	.26	.11	.13	.12	.13	.12	.09
MgO	.59	.85	1.09	.98	.40	.41	.39	.53
CaO	1.98 [1]	2.22	2.22 [2]	2.17 [3]	1.34	1.14	1.45	1.39
Na_2O	3.26	3.19	3.31	3.31	3.59	3.59	3.60	2.88
K_2O	4.53	4.41	3.98	4.10	4.09	3.99	4.16	4.61
P_2O_5	.10	.26	.27	.24	.06	.01	.07	.09
Each sum = 100.00.								

[1] Includes .08% BaO and .01% SrO.
[2] Includes .06% BaO and .02% SrO.
[3] Includes .06% BaO and .02% SrO.

GROUP II.

	Plutonics.					Effusives.		
	9	10	11	12	13	14	15	16
	Nordmarkite (Osann and Washington).	Pulaskite (Osann and Washington).	Akerite (Osann and Washington).	Average Alkaline Syenite, including 7 Nordmarkites, 5 Pulaskites, 9 Akerites, and 3 Laurvikites.	All Syenite, including five Types of "Alkaline" Syenite.	Trachyte (Osann and Rosenbusch).	Keratophyre (Osann and Washington).	Quartz Keratophyre (Rosenbusch).
No. of Analyses.	7	5	8	23	50	48	7	13
SiO_2	64.36	61.86	61.96	61.99	60.19	60.68	61.51	75.45
TiO_2	.45	.15	.99	.56	.67	.38	.45	.17
Al_2O_3	16.81	19.07	17.07	17.93	16.28	17.74	17.37	13.11
Fe_2O_3	1.08	2.65	2.35	2.22	2.74	2.64	1.92	1.14
FeO	2.71	1.49	3.37	2.29	3.28	2.62	3.35	.66
MnO	.15	.01	.09	.08	.14	.06	.01	.29
MgO	.72	.55	1.38	.96	2.49	1.12	1.26	34
CaO	1.55	1.47	3.41	2.55	4.30	3.09	1.08	.83
Na_2O	5.76	6.45	4.65	5.54	3.98	4.43	5.23	5.88
K_2O	5.62	5.75	3.80	4.98	4.49	5.74	5.29	1.26
H_2O	.70	.47	.93	.76	1.16	1.26	2.45	.69
P_2O_5	09	.08	....	.14	.28	.24	.08	.18
Calculated as Water-free.								
SiO_2	64.81	62.15	62.55	62.46	60.90	61.46	63.06	75.98
TiO_2	.45	.15	1.00	.56	.68	.38	.46	.17
Al_2O_3	16.93	19.16	17.23	18.07	16.47	17.97	17.81	13.20
Fe_2O_3	1.09	2.66	2.37	2.24	2.77	2.67	1.97	1.15
FeO	2.73	1.50	3.40	2.31	3.32	2.66	3.43	.66
MnO	.15	.01	.09	.08	.14	.06	.01	.29
MgO	.73	.55	1.39	.97	2.52	1.13	1.29	.34
CaO	1.56	1.48	3.44	2.57	4.35	3.13	1.11	.84
Na_2O	5.80	6.48	4.69	5.58	4.03	4.49	5.36	5.92
K_2O	5.66	5.78	3.84	5.02	4.54	5.81	5.42	1.27
P_2O_5	.09	.08	....	.14	.28	.24	.08	.18
Each sum = 100.00.								

GROUP III.

	Plutonic.	Effusive.	Plutonic.	Effusive.
	17	**18**	**19**	**20**
	Laurvikite (Osann).	Rhomb-porphyry (Washington).	Monzonite (Osann and Washington).	Latite (Ransome and Daly).
No. of Analyses.	3	7	12	10
SiO_2	57.45	57.45	55.25	57.65
TiO_2	....	....	.60	1.00
Al_2O_3	21.11	19.53	16.53	16.68
Fe_2O_3	2.89	6.47	3.03	2.29
FeO	2.39		4.37	4.07
MnO	....	....	.15	.10
MgO	1.06	1.28	4.20	3.22
CaO	4.10	3.11	7.19	5.74 [1]
Na_2O	5.89	6.35	3.48	3.59
K_2O	3.87	4.46	4.11	4.39
H_2O	.70	1.35	.66	.91 [2]
P_2O_5	.54	....	.43	.36
Calculated as Water-free.				
SiO_2	57.85	58.24	55.62	58.18
TiO_2	....	....	.60	1.01
Al_2O_3	21.26	19.79	16.64	16.84
Fe_2O_3	2.91	6.56	3.05	2.31
FeO	2.41		4.40	4.11
MnO	....	....	.15	.10
MgO	1.07	1.30	4.23	3.25
CaO	4.13	3.15	7.24	5.79 [1]
Na_2O	5.93	6.44	3.50	3.62
K_2O	3.90	4.52	4.14	4.43
P_2O_5	.54	....	.43	.36
Each sum = 100.00.				

[1] Includes .16% BaO and .07% SrO.
[2] Includes .14% CO_2.

GROUP IV.

	Plutonics.				Effusives.		
	21	22	23	24	25	26	27
	Foyaite (Osann and Rosenbusch).	Urtite (Osann).	Laurdalite (Osann).	Nephelite syenite (Osann).	Phonolite (Osann, Clarke, and Lacroix).	Leucite Phonolite (Osann and Washington).	Leucitophyre (Washington and Rosenbusch).
No. of Analyses.	10	3	3	43	25	4	8
SiO_2	56.11	45.61	54.36	54.63	57.45	54.89	49.83
TiO_2	.45	....	1.30	.86	.41	....	.71
Al_2O_3	21.33	27.76	19.99	19.89	20.60	21.28	19.00
Fe_2O_3	1.87	3.67	2.79	3.37	2.35	3.04	3.17
FeO	1.47	.50	2.58	2.20	1.03	1.49	3.59
MnO	.05	.15	.18	.35	.13	.01	.17
MgO	.55	.19	1.72	.87	.30	.66	1.79
CaO	1.72	1.73	2.96	2.51	1.50	2.31	5.69
Na_2O	8.48	16.25	8.28	8.26	8.84	5.62	7.19
K_2O	6.46	3.72	4.98	5.46	5.23	8.39	6.15
H_2O	1.50	.42	.22	1.35	2.04	2.31	1.93
P_2O_5	.01	....	.64	.25	.12	....	.78
Calculated as Water-free.							
SiO_2	56.96	45.80	54.48	55.38	58.65	56.19	50.82
TiO_2	.46	....	1.30	.87	.42	....	.72
Al_2O_3	21.65	27.88	20.03	20.16	21.03	21.78	19.38
Fe_2O_3	1.90	3.68	2.80	3.42	2.40	3.11	3.23
FeO	1.49	.50	2.59	2.23	1.05	1.53	3.66
MnO	.05	.15	.18	.35	.13	.01	.17
MgO	.56	.19	1.72	.88	.31	.68	1.83
CaO	1.75	1.74	2.97	2.54	1.53	2.36	5.80
Na_2O	8.61	16.32	8.30	8.38	9.02	5.75	7.33
K_2O	6.56	3.74	4.99	5.54	5.34	8.59	6.27
P_2O_5	.01	....	.64	.25	.12	....	.79
Each sum = 100.00.							

GROUP V.

	Pl.	Ef.	Plutonics			Effusives.				
	28	29	30	31	32	33	34	35	36	37
	Granodiorite (Osann and Clarke).	Dacite (Osann and Rosenbusch).	Quartz Diorite (Osann and Washington).	Diorite, includ'g Quartz Diorite (Osann).	Diorite, exclud'g Quartz Diorite (Osann).	All Andesite (Osann).	Augite Andesite (Osann).	Hypersthene Andesite (Osann).	Hornblende (Amphibole) Andesite (Osann).	Mica Andesite (Osann).
No. of Analyses.	12	30	20	89	70	87	33	20	24	10
SiO_2	65.10	66.91	59.47	58.38	56.77	59.59	57.50	59.48	61.12	62.25
TiO_2	.54	.33	.64	.80	.84	.77	.79	.48	.42	1.65
Al_2O_3	15.82	16.62	16.52	16.28	16.67	17.31	17.33	17.38	17.65	16.10
Fe_2O_3	1.64	2.44	2.63	2.98	3.16	3.33	3.78	2.96	2.89	3.62
FeO	2.66	1.33	4.11	4.11	4.40	3.13	3.62	3.67	2.40	2.20
MnO	.05	.04	.08	.13	.13	.18	.22	.15	.15	.21
MgO	2.17	1.22	3.75	3.88	4.17	2.75	2.86	3.28	2.44	2.03
CaO	4.66	3.27	6.24	6.38	6.74	5.80	5.83	6.61	5.80	4.05
Na_2O	3.82	4.13	2.98	3.34	3.39	3.58	3.53	3.41	3.83	3.55
K_2O	2.29	2.50	1.93	2.09	2.12	2.04	2.36	1.64	1.72	2.44
H_2O	1.09	1.13	1.39	1.37	1.36	1.26	1.88	.74	1.43	1.50
P_2O_5	.16	.08	.26	.26	.25	.26	.30	.20	.15	.40
Calculated as Water-free.										
SiO_2	65.82	67.67	60.31	59.19	57.56	60.35	58.65	59.92	62.01	63.20
TiO_2	.55	.33	.65	.81	.85	.78	.80	.48	.43	1.67
Al_2O_3	15.99	16.81	16.75	16.51	16.90	17.54	17.67	17.51	17.91	16.35
Fe_2O_3	1.66	2.47	2.67	3.02	3.20	3.37	3.85	2.98	2.93	3.67
FeO	2.69	1.35	4.17	4.17	4.46	3.17	3.69	3.70	2.44	2.23
MnO	.05	.04	.08	.13	.13	.18	.22	.15	.15	.21
MgO	2.19	1.23	3.80	3.93	4.23	2.78	2.90	3.31	2.48	2.06
CaO	4.71	3.31	6.33	6.47	6.83	5.87	5.92	6.66	5.88	4.11
Na_2O	3.86	4.18	3.02	3.39	3.44	3.63	3.60	3.44	3.88	3.61
K_2O	2.32	2.53	1.96	2.12	2.15	2.07	2.40	1.65	1.74	2.48
P_2O_5	.16	.08	.26	.26	.25	.26	.30	.20	.15	.41
Each sum = 100.00.										

GROUP VI.

	Plutonics.		Effusives.					
	38	39	40	41	42	43	44	45
	All Norite (Osann and Walker).	All Gabbro (Osann).	All Basalt, including 161 Basalts, 17 Olivine Diabases, 11 Melaphyres, and 9 Dolerites (Osann).	Basalt, as named by Authors (including also Anamesite, Tachylite, etc.) (Osann).	Diabase (Osann).	Olivine Diabase (Osann).	Melaphyre (Osann).	Dolerite (Osann).
No. of Analyses.	7	41	198	161	20	17	11	9
SiO_2	50.16	48.24	49.06	48.78	50.12	50.10	50.60	49.50
TiO_2	1.64	.97	1.36	1.39	1.41	1.25	.68	1.42
Al_2O_3	18.51	17.88	15.70	15.85	15.68	14.43	17.40	14.37
Fe_2O_3	1.88	3.16	5.38	5.37	4.55	5.06	4.57	6.55
FeO	9.29	5.95	6.37	6.34	6.73	6.31	6.29	5.84
MnO	.14	.13	.31	.29	.23	.25	.46	.17
MgO	5.97	7.51	6.17	6.03	5.85	7.32	4.89	7.75
CaO	7.90	10.99	8.95	8.91	8.80	9.53	8.09	9.96
Na_2O	2.72	2.55	3.11	3.18	2.95	2.75	3.23	2.50
K_2O	.80	.89	1.52	1.63	1.38	.73	1.76	.84
H_2O	.76	1.45	1.62	1.76	1.93	2.00	1.83	.66
P_2O_5	.23	.28	.45	.47	.37	.27	.20	.44
Calculated as Water-free.								
SiO_2	50.54	48.95	49.87	49.65	51.11	51.12	51.54	49.83
TiO_2	1.65	.98	1.38	1.41	1.44	1.27	.69	1.43
Al_2O_3	18.65	18.15	15.96	16.13	15.99	14.73	17.73	14.47
Fe_2O_3	1.90	3.21	5.47	5.47	4.64	5.16	4.66	6.59
FeO	9.36	6.04	6.47	6.45	6.86	6.44	6.41	5.88
MnO	.14	.13	.32	.30	.23	.25	.47	.17
MgO	6.02	7.62	6.27	6.14	5.96	7.47	4.99	7.80
CaO	7.96	11.15	9.09	9.07	8.97	9.73	8.24	10.02
Na_2O	2.74	2.59	3.16	3.24	3.01	2.81	3.29	2.52
K_2O	.81	.90	1.55	1.66	1.41	.74	1.78	.85
P_2O_5	.23	.28	.46	.48	.38	.28	.20	.44
Each sum = 100.00.								

GROUP VII.

	Plutonics.				
	46	47	48	49	50
	Gabbro, excluding Olivine Gabbro (Osann).	Olivine Gabbro (Osann).	Norite, excluding Olivine Norite (Osann and Walker).	Olivine Norite (Osann).	Anorthosite (Osann and Washington).
No. of Analyses.	24	17	5	2	12
SiO_2	49.50	46.49	50.08	50.38	50.40
TiO_2	.84	1.17	1.44	2.04	.15
Al_2O_3	18.00	17.73	18.62	18.27	28.30
Fe_2O_3	2.80	3.66	2.35	.73	1.06
FeO	5.80	6.17	8.87	10.35	1.12
MnO	.12	.17	.11	.20	.05
MgO	6.62	8.86	6.22	5.32	1.25
CaO	10.64	11.48	7.89	7.91	12.46
Na_2O	2.82	2.16	2.53	3.18	3.67
K_2O	.98	.78	.71	1.02	.74
H_2O	1.60	1.04	1.01	.26	.75
P_2O_5	.28	.29	.17	.34	.05
Calculated as Water-free.					
SiO_2	50.31	46.97	50.60	50.51	50.78
TiO_2	.85	1.18	1.45	2.05	.15
Al_2O_3	18.30	17.92	18.81	18.32	28.51
Fe_2O_3	2.85	3.70	2.37	.73	1.07
FeO	5.89	6.24	8.96	10.38	1.13
MnO	.12	.17	.11	.20	.05
MgO	6.73	8.96	6.28	5.33	1.26
CaO	10.81	11.60	7.97	7.93	12.55
Na_2O	2.86	2.18	2.56	3.19	3.70
K_2O	1.00	.79	.72	1.02	.75
P_2O_5	.28	.29	.17	.34	.05
Each sum = 100.00.					

GROUP VIII.

	Plutonics.							Effusive.
	51	52	53	54	55	56	57	58
	Lherzolite (Osann).	Websterite (Osann).	Wehrlite (Osann).	Harzburgite, including Saxonite (Osann and Washington).	Dunite (Washington).	Pyroxenite (Osann).	All Peridotite (Osann).	Picrite (Osann).
No of Analyses.	4	4	3	4	3	4	49	3
SiO_2	42.09	53.65	48.13	43.85	40.06	49.82	44.39	43.24
TiO_2	.12	.14	.87	....	....	1.46	.88	....
Al_2O_3	4.83	1.66	6.50	5.00	.57	5.12	5.14	15.19
Fe_2O_3	4.98	1.90	2.01	2.54	2.29	1.83	3.88	8.62
FeO	4.58	5.35	11.73	6.30	7.32	7.44	6.70	7.89
MnO	.06	.17	.08	.12	.24	.09	.19	....
MgO	31.80	22.57	21.01	36.96	46.62	19.55	29.17	8.56
CaO	6.37	13.37	6.17	2.70	.35	13.00	6.31	13.78
Na_2O	1.02	.20	1.15	....	.01	.37	.64	.54
K_2O	.29	.07	.58	....	....	.21	.76	.48
H_2O	3.85	.85	1.62	2.53 [1]	2.53	1.06	1.80	1.21
P_2O_5	.01	.07	.15	....	.01	.05	.14	.49
Calculated as Water-free.								
SiO_2	43.78	54.11	48.93	44.99	41.10	50.36	45.20	43.77
TiO_2	.12	.14	.88	....	....	1.48	.90	....
Al_2O_3	5.02	1.67	6.61	5.13	.58	5.17	5.25	15.37
Fe_2O_3	5.18	1.92	2.04	2.61	2.35	1.85	3.95	8.72
FeO	4.77	5.40	11.92	6.46	7.51	7.52	6.82	7.99
MnO	.06	.17	.08	.12	.25	.09	.19	....
MgO	33.08	22.76	21.36	37.92	47.83	19.76	29.70	8.66
CaO	6.62	13.49	6.27	2.77	.36	13.14	6.43	13.95
Na_2O	1.06	.20	1.17	....	.01	.37	.65	.55
K_2O	.30	.07	.59	....	....	.21	.77	.49
P_2O_5	.01	.07	.15	....	.01	.05	.14	.50
Each sum = 100.00.								

[1] Loss on ignition.

GROUP IX.

	Plutonic.	Effusives.		
	59	60	61	62
	Essexite (Osann and Rosenbusch).	Trachydolerite (Rosenbusch).	Limburgite (Zirkel).	Augitite (Osann, Washington, and Rosenbusch).
No. of Analyses.	11	4	7	6
SiO_2	48.40	54.81	41.69	42.25
TiO_2	1.71	.42	.67	2.52
Al_2O_3	16.67	20.01	14.80	16.26
Fe_2O_3	5.31	3.98	15.04	8.43
FeO	6.03	1.93		5.46
MnO	.15	....	....	....
MgO	4.48	2.32	8.64	5.49
CaO	9.05	5.60	11.98	9.75
Na_2O	4.45	5.86	3.52	4.45
K_2O	2.13	3.13	1.17	1.92
H_2O	.95	1.46	2.36	2.43
P_2O_5	.67	.48	.13	1.04
Calculated as Water-free.				
SiO_2	48.86	55.62	42.69	43.30
TiO_2	1.73	.43	.68	2.58
Al_2O_3	16.83	20.31	15.18	16.67
Fe_2O_3	5.36	4.04	15.43	8.64
FeO	6.09	1.96		5.59
MnO	.15	....	....	....
MgO	4.52	2.35	8.85	5.63
CaO	9.14	5.68	12.27	9.99
Na_2O	4.49	5.94	3.58	4.56
K_2O	2.15	3.18	1.19	1.97
P_2O_5	.68	.49	.13	1.07
Each sum = 100.00.				

GROUP X.

	Plutonics.		Effusives.					
	63	64	65	66	67	68	69	70
	Theralite (Osann).	Shonkinite (Pirsson).	All Tephrite.	All Basanite.	Nephelite Tephrite (Osann).	Leucite Tephrite (Osann and Washington).	Nephelite Basanite (Osann).	Leucite Basanite (Osann and Washington).
No. of Analyses.	6	6	24	20	4	20	16	4
SiO_2	45.61	48.66	49.14	44.41	46.91	49.90	44.20	45.34
TiO_2	1.96	.97	1.00	1.56	1.81	.16	1.64	1.30
Al_2O_3	14.35	12.36	16.57	15.81	15.25	16.94	15.64	16.59
Fe_2O_3	6.17	3.08	3.65	4.66	7.70	3.02	4.35	5.83
FeO	4.03	5.86	6.68	5.85	4.06	7.15	6.14	4.76
MnO	.19	.13	.30	.14	1.43	.23	.19	.01
MgO	6.05	8.09	3.98	8.20	2.95	4.22	8.89	5.43
CaO	9.49	10.46 [1]	9.88	10.12	9.36	10.04	9.74	11.64
Na_2O	5.12	2.71	2.57	3.81	4.25	2.24	4.03	2.93
K_2O	3.69	5.15	3.39	2.37	2.63	3.57	1.83	4.55
H_2O	2.60	1.46	2.00	2.42	2.51	1.74	2.67	1.12
P_2O_5	.74	1.07	.84	.65	1.14	.79	.68	.50
Calculated as Water-free.								
SiO_2	46.83	49.38	50.15	45.51	48.12	50.79	45.41	45.86
TiO_2	1.98	.98	1.02	1.60	1.86	.16	1.68	1.31
Al_2O_3	14.73	12.55	16.90	16.20	15.65	17.24	16.07	16.78
Fe_2O_3	6.34	3.12	3.72	4.78	7.89	3.07	4.47	5.90
FeO	4.14	5.95	6.82	5.99	4.16	7.28	6.31	4.81
MnO	.19	.13	.31	.14	1.47	.23	.20	.01
MgO	6.22	8.21	4.06	8.41	3.02	4.30	9.13	5.49
CaO	9.75	10.62 [2]	10.08	10.37	9.60	10.22	10.01	11.77
Na_2O	5.27	2.75	2.62	3.90	4.36	2.28	4.14	2.96
K_2O	3.79	5.23	3.46	2.43	2.70	3.63	1.88	4.60
P_2O_5	.76	1.08	.86	.67	1.17	.80	.70	.51
Each sum = 100.00.								

[1] Includes .40% BaO and .09% SrO.

[2] Includes .41% BaO and .09% SrO.

GROUP XI.

	Plutonics.		Effusives.		Plutonic.	Effusives.	
	71	72	73	74	75	76	77
	Fergusite (Pirsson).	Missourite (Pirsson and Daly).	Leucite Basalt (Osann and Rosenbusch).	Leucitite (Osann and Rosenbusch).	Ijolite (Osann).	Nephelinite (Rosenbusch).	Nephelite Basalt (Osann).
No. of Analyses.	1	2	7	7	5	9	26
SiO_2	51.70	44.27	46.47	47.72	43.51	41.17	39.87
TiO_2	.23	1.37	1.33	.52	1.07	1.35	1.50
Al_2O_3	14.50	10.73	15.97	18.19	19.54	16.83	13.58
Fe_2O_3	5.07	3.63	5.97	4.74	3.77	7.61	6.71
FeO	3.58	5.87	4.27	3.90	3.88	6.64	6.43
MnO	.01	.06	.01	.06	.16	.16	.21
MgO	4.55	13.05	5.87	3.45	2.94	3.72	10.46
CaO	7.40 [1]	11.46 [2]	10.54	7.27	9.89	10.12	12.36
Na_2O	2.93	1.07	1.69	4.51	10.58	6.45	3.85
K_2O	7.60	4.43	4.83	7.66	2.26	2.49	1.87
H_2O	2.25	3.23	2.32	1.51	.86	2.42	2.22 [3]
P_2O_5	.18	.83	.73	.47	1.54	1.04	94.
Calculated as Water-free.							
SiO_2	52.89	45.75	47.58	48.45	43.89	42.19	40.77
TiO_2	.24	1.41	1.36	.53	1.08	1.38	1.53
Al_2O_3	14.83	11.09	16.35	18.47	19.71	17.25	13.88
Fe_2O_3	5.18	3.75	6.11	4.81	3.80	7.79	6.86
FeO	3.66	6.07	4.37	3.96	3.91	6.81	6.57
MnO	.01	.06	.01	.06	.16	.17	.21
MgO	4.65	13.49	6.01	3.50	2.97	3.81	10.73
CaO	7.57 [4]	11.85 [5]	10.79	7.38	9.98	10.37	12.65
Na_2O	3.00	1.10	1.73	4.58	10.67	6.61	3.94
K_2O	7.79	4.57	4.94	7.78	2.28	2.55	1.90
P_2O_5	.18	.86	.75	.48	1.55	1.07	.96
Each sum = 100.00.							

[1] Includes .30% BaO and .07% SrO. [2] Includes .48% BaO and .18% SrO.
[3] Includes .29% CO_2. [4] Includes .31 % BaO and .07 % SrO.
[5] Includes .50% BaO and .19% SrO.

GROUP XII.

	Plutonics.		
	78	79	80
	Alaskite (Osann).	Diorite of Electric Peak (Rosenbusch).	Malignite (Osann and Daly).
No. of Analyses.	3	10	4
SiO_2	76.47	62.21	50.34
TiO_2	.07	.60	.34
Al_2O_3	13.03	16.45	14.75
Fe_2O_3	1.04	2.53	4.18
FeO		2.89	2.75
MnO	.01	.02	.11
MgO	.06	3.32	4.23
CaO	.45	4.96	10.43
Na_2O	3.53	3.88 [1]	5.27
K_2O	4.81	2.21	5.21
H_2O	.52	.80 [2]	1.20
P_2O_5	.01	.13	1.19
Calculated as Water-free.			
SiO_2	76.87	62.71	50.95
TiO_2	.07	.60	.35
Al_2O_3	13.10	16.58	14.93
Fe_2O_3	1.05	2.55	4.23
FeO		2.92	2.78
MnO	.01	.02	.11
MgO	.06	3.35	4.28
CaO	.45	5.00	10.56
Na_2O	3.55	3.91 [1]	5.33
K_2O	4.83	2.23	5.27
P_2O_5	.01	.13	1.21
Each sum = 100.00.			

[1] Includes .07% Li_2O.

[2] Includes .05% Cl and .05% SO_3.

GROUP XIII.

	Effusives.						
	81	82	83	84	85	86	87
	Rhyolite of Yellowstone Park (Iddings).	Basalt of Hawaii (Osann).	Banakite (Osann).	Shoshonite (Osann).	Absarokite (Osann).	Leucite Absarokite (Osann).	Melilite Basalt (Osann).
No. of Analyses.	10	11	4	8	5	2	6
SiO_2	74.04	48.36	52.04	53.56	50.11	47.45	36.19
TiO_2	.18	.66	.76	.82	.96	.81	7.11
Al_2O_3	13.19	15.40	17.65	17.88	13.04	11.43	10.52
Fe_2O_3	1.35	6.48	4.66	4.51	4.58	3.22	8.48 [1]
FeO	1.01	10.07	2.75	3.05	3.94	5.78	5.97
MnO	.04	.80	.13	.07	.11	.12	....
MgO	.32	4.19	3.33	3.62	9.27	14.60	14.59
CaO	1.19	8.69	5.11	6.45	7.63	8.18	9.88
Na_2O	3.88	3.34	4.10	3.41	1.94	2.32	3.28
K_2O	3.75	1.30	5.03	3.76	4.15	2.99	2.03
H_2O	1.02 [2]	.43	3.74	2.32	3.58	2.50	1.94 [3]
P_2O_5	.03	.28	.70	.55	.69	.60	.01
Calculated as Water-free.							
SiO_2	74.80	48.57	54.06	54.84	51.97	48.67	36.90
TiO_2	.18	.66	.79	.84	1.00	.83	7.25
Al_2O_3	13.33	15.47	18.34	18.31	13.52	11.73	10.73
Fe_2O_3	1.37	6.51	4.84	4.62	4.74	3.30	8.65 [4]
FeO	1.02	10.11	2.85	3.12	4.08	5.93	6.09
MnO	.04	.80	.14	.07	.12	.12	....
MgO	.32	4.21	3.46	3.70	9.62	14.97	14.88
CaO	1.20	8.73	5.31	6.60	7.91	8.39	10.08
Na_2O	3.92	3.35	4.26	3.49	2.01	2.38	3.34
K_2O	3.79	1.31	5.22	3.85	4.31	3.06	2.07
P_2O_5	.03	.28	.73	.56	.72	.62	.01
Each sum = 100.00							

[1] Includes 2.85 % Cr_2O_3.
[2] Includes .02 % Li_2O and .23 % SO_3.
[3] Loss on ignition.
[4] Includes 2.47 % Cr_2O_3.

GROUP XIV.

Dike-rocks.					
	88	89	90	91	92
	Granite-aplite (Osann and Washington).	Bostonite (Rosenbusch and Washington).	Grorudite (Osann and Washington).	Sölysbergite (Osann and Washington).	Tinguaite (Osann and Washington).
No. of Analyses.	15	5	5	8	15
SiO_2	75.00	61.32	70.91	62.16	55.02
TiO_2	.30	.89	.48	.31	.36
Al_2O_3	13.14	18.43	11.50	17.58	20.42
Fe_2O_3	.58	3.84	4.58	3.05	3.06
FeO	.40	1.60	1.88	1.80	1.82
MnO	.07	.01	.39	.18	.22
MgO	.30	.46	.11	.48	.59
CaO	1.13	1.45	.39	1.11	1.67
Na_2O	3.54	5.75	5.43	7.30	8.63
K_2O	4.80	4.94	4.08	4.95	5.38
H_2O	.71	1.31	.25	1.04	2.77
P_2O_5	.03	....	....	.04	.06
Calculated as Water-free.					
SiO_2	75.54	62.14	71.09	62.82	56.59
TiO_2	.30	.90	.48	.31	.37
Al_2O_3	13.23	18.67	11.53	17.77	21.00
Fe_2O_3	.58	3.89	4.59	3.08	3.15
FeO	.40	1.62	1.89	1.82	1.87
MnO	.07	.01	.39	.18	.23
MgO	.30	.47	.11	.49	.61
CaO	1.14	1.47	.39	1.12	1.72
Na_2O	3.57	5.82	5.44	7.37	8.87
K_2O	4.84	5.01	4.09	5.00	5.53
P_2O_5	.03	....	....	.04	.06
Each sum = 100.00.					

GROUP XV.

	Dike-rocks.					
	93	94	95	96	97	98
	Minette (Osann and Clarke).	Kersantite (Osann and Rosenbusch).	Vogesite (Osann).	Camptonite (Osann).	Monchiquite (Osann).	Alnöite (Osann and Washington).
No. of Analyses.	10	20	4	15	16	6
SiO_2	49.45	50.79	52.62	40.70	45.17	32.31
TiO_2	1.23	1.02	.54	3.86	1.90	1.41
Al_2O_3	14.41	15.26	14.86	16.02	14.78	9.50
Fe_2O_3	3.39	3.29	3.60	5.43	5.10	5.42
FeO	5.01	5.54	4.18	7.84	5.05	6.34
MnO	.13	.07	.84	.16	.35	.01
MgO	8.26	6.33	8.55	5.43	6.26	17.43
CaO	6.73	5.73	5.86	9.36	11.06	13.58
Na_2O	2.54	3.12	3.21	3.23	3.69	1.42
K_2O	4.69	2.79	2.83	1.76	2.73	2.70
H_2O	3.04 [1]	5.71 [2]	2.70	5.59 [3]	3.40	7.50 [4]
P_2O_5	1.12	.35	.21	.62	.51	2.38
Calculated as Water-free.						
SiO_2	50.99	53.87	54.08	43.10	46.76	34.93
TiO_2	1.27	1.08	.56	4.09	1.96	1.52
Al_2O_3	14.86	16.18	15.28	16.97	15.30	10.27
Fe_2O_3	3.50	3.48	3.70	5.76	5.28	5.86
FeO	5.17	5.88	4.29	8.30	5.23	6.85
MnO	.13	.07	.86	.16	.36	.01
MgO	8.53	6.71	8.79	5.76	6.48	18.84
CaO	6.95	6.09	6.02	9.92	11.45	14.68
Na_2O	2.62	3.31	3.30	3.42	3.82	1.53
K_2O	4.84	2.96	2.90	1.86	2.83	2.92
P_2O_5	1.14	.37	.22	.66	.53	2.59
Each sum = 100.00.						

[1] Includes .61% CO_2. [2] Includes 2.61% CO_2.
[3] Includes 2.97% CO_2. [4] Includes 4.35% CO_2.

Index to Table II.

Absarokite 85
Akerite 11
Alaskite 78
Alnöite 98
Amphibole andesite 36
Andesite (all) 33
Anorthosite 50
Augite andesite 34
Augitite 62
Banakite 83
Basalt (all) 40
Basalt as named by authors . . 41
Basalt of Hawaiian Islands . . . 82
Basanite (all) 66
Bostonite 89
Camptonite 96
Dacite 29
Diabase 42
Diorite, including quartz diorite . 31
Diorite, excluding quartz diorite . 32
Diorite of Electric Peak 79
Dolerite 45
Dunite 55
Eleolite syenite 24
Essexite 59
Fergusite 71
Foyaite 21
Gabbro (all) 39
Gabbro, excluding olivine gabbro 46
Granite of all periods 4
Granite younger than the Pre-Cambrian 3
Granites (Pre-Cambrian, including 16 analyses of Swedish types) 1
Granites (Pre-Cambrian, of Sweden) 2
Granite-aplite 88
Granodiorite 28
Grorudite 90
Harzburgite 54
Hornblende andesite 36
Hypersthene andesite 35
Ijolite 75
Keratophyre 15
Kersantite 94
Latite 20
Laurdalite 23
Laurvikite 17
Leucite absarokite 86
Leucite basalt 73
Leucite basanite 70
Leucite phonolite 26
Leucite tephrite 68
Leucitite 74
Leucitophyre 27
Lherzolite 51
Limburgite 61
Liparite (all) 5
Liparite, as named by authors . 6
Malignite 80
Melaphyre 44
Melilite basalt 87
Mica andesite 37
Minette 93
Missourite 72
Monchiquite 97
Monzonite 19
Nephelite basalt 77
Nephelite basanite 69
Nephelite syenite 24
Nephelite tephrite 67
Nephelinite 76
Nordmarkite 9
Norite (all) 38
Norite, excluding olivine norite . 48
Olivine diabase 43
Olivine gabbro 47
Olivine norite 49
Peridotite (all) 57
Phonolite 25
Picrite 58
Pulaskite 10
Pyroxenite 56
Quartz diorite 30
Quartz keratophyre 16
Quartz porphyry 8
Rhomb-porphyry 18
Rhyolite, as named by authors . 7
Rhyolite of Yellowstone Park . 81
Saxonite 54
Shonkinite 64
Shoshonite 84
Sölvsbergite 91
Syenite (all) 13
Syenite (alkaline) 12
Tephrite (all) 65
Theralite 63

Tinguaite	**92**	Vogesite	**95**
Trachydolerite	**60**	Websterite	**52**
Trachyte	**14**	Wehrlite	**53**
Urtite	**22**		

Average Specific Gravities of Certain Types.

The average specific gravities of holocrystalline types have been calculated, with result shown in the following accessory table. Most of the determinations were taken from Osann's book.

	Number of Specimens averaged.	Average Specific Gravity.
Granite	58	2.660
Granodiorite	5	2.740
Syenite	11	2.773
Monzonite	2	2.805
Nephelite syenite	13	2.600
Diorite	17	2.861
Gabbro	19	2.933
Olivine gabbro	4	2.948
Anorthosite	6	2.715
Peridotite	21	3.176
Essexite	2	2.862
Theralite	3	2.917
Malignite	4	2.884

Some Applications.

The uses to which the averages may be put are diverse and, in certain instances, direct and important. A brief note in this place will indicate something of the range of the considerations affected.

1. The writer has found from personal experience that the averages have been of decided benefit in showing the chemical individuality and true nature of the igneous-rock types as actually mapped. To student and investigator alike such averages are, for many purposes, more valuable than single analyses. They help to show that eruptive rocks

do not form an infinite series, but that the varieties cluster about "center-points." Osann's great compilation proves that Rosenbusch's classification is an objective and "natural" one to a highly useful degree.

2. The obvious error involved in computing "the average composition of the primitive crust of the earth," or "the average igneous rock," or "the mean composition of the accessible parts of the earth's crust," by averaging a large number of analyses compiled at random, has not deterred a goodly number of authors from using such results as those deduced by Clarke, Washington, and Harker. These averages are bound to breed further errors when used as a basis for quantitative studies in geology or oceanography. The discovery of "the average igneous rock" is of the highest importance for many problems such as the chemical denudation of the lands and the chemical evolution of the ocean. The mean composition of the accessible crystalline rocks of the globe must ultimately be obtained by taking account of the relative volumes of the different rock-types. In computing the mean the average analyses for the principal individual species must be employed. Since the only approach to success is through the quantitative study of geological maps and memoirs, it is clear that for many years to come the averages for the types recognized in Rosenbusch's system are to be basal to the calculation.

A glance at Table II. shows, however, that this new world-average will differ little from the earlier world-averages with respect to one oxide, namely, soda. For each of the areally and volumetrically important rock-types the average soda never departs far from a mean of about three and one half per cent. The soda in the averages of Clarke, Washington, and Harker (calculated as water-free) is, respectively, 3.63 per cent, 3.34 per cent, and 3.90 per cent.[1] The agreement is fortunate, since, for example, the quantitative problem relative to the sodium in the ocean can be pursued without waiting for the close determination of "the average igneous rock." Incidentally, it may be remarked that the estimates of Joly[2] and Sollas[3] regarding the age of the ocean, as determined by the sodium content, need revision, since neither author has allowed for the great variations in the area of the lands during geological time.

3. The recurrence of the main types of igneous rock in every continent shows that general processes of differentiation have been at work

[1] F. W. Clarke, Bull. 228, U. S. Geol. Survey, 1904, p. 16.

[2] J. Joly, Sci. Trans. Roy. Dublin Society, **7**, 23 (1899).

[3] W. J. Sollas, Quart. Jour. Geol. Soc., Presidential Address, **65**, p. lxxix (1909).

from the earliest recorded time. There is no reason to doubt that the diorite or the nephelite syenite of the pre-Cambrian periods have generally owed their origin to the same physico-chemical reactions as those responsible for the Mesozoic or Tertiary diorite or nephelite syenite. If this be true, the world-averages for the different principal types should be so many tests of theoretical conclusions as to the causes of the differentiation of those types. The question as to the derivation of augite andesite from basalt through fractional crystallization has been thus tested, with, so far as this test goes, an affirmative answer.[4]

Sometimes the averages themselves suggest lines of thought. For example, the average granite analysis (calculated water-free; 236 analyses) is close to the average of four analyses of the glassy base of augite andesite (calculated as water-free). The comparison may be made from the following table:

	Granite of all Periods.	Ground-mass (base) of Augite andesite.
No. of Analyses	**236**	**4**
	per cent.	per cent.
SiO_2	70.47	69.31
TiO_2	.39	....
Al_2O_3	14.90	17.11
Fe_2O_3	1.63	2.15
FeO	1.68	.60
MnO	.13	....
MgO	.98	.70
CaO (BaO and SrO)	2.17	2.63
Na_2O	3.31	3.20
K_2O	4.10	4.30
P_2O_5	.24	....
	100.00	100.00

The exact meaning of the correspondence between the two averages may not be discussed here; but it does suggest an explanation of the

[4] Journal of Geology, **16**, 401 (1908).

common association of granites (and liparites) with andesites (and diorites) in nature. The question is open as to whether the primitive granite-liparite magma was not a polar differentiate of an andesitic magma, preferably by a settling-out of the phenocrystic constituents (in solid or liquid phases)from the andesitic magma.

Other related questions are raised by the comparison of the mean of average granite and average basalt with average diorite (including quartz diorite).

	1. Average Granite.	2. Average Basalt.	3. Mean of 1 and 2.	4. Average Diorite.
No. of Analyses	**236**	**161**	—	**89**
	per cent.	per cent.	per cent.	per cent.
SiO_2	70.47	49.65	60.06	59.19
TiO_2	.39	1.41	.90	.81
Al_2O_3	14.90	16.13	15.52	16.51
Fe_2O_3	1.63	5.47	3.55	3.02
FeO	1.68	6.45	4.06	4.17
MnO	.13	.30	.21	.13
MgO	.98	6.14	3.56	3.93
CaO	2.17 [1]	9.07	5.62	6.47
Na_2O	3.31	3.24	3.28	3.39
K_2O	4.10	1.66	2.88	2.12
P_2O_5	.24	.48	.36	. 26
	100.00	100.00	100.00	100.00

[1] Includes .06% BaO and .02% SrO.

Is basalt the basic pole, granite the acid pole, of a primitive differentiation of diorite magma? Is diorite the product of mixture of primitive, granitic crust and primary basalt still molten beneath? Though the averages give no answer, they tend to keep these fundamental queries before the eye of the petrologist.

4. The averages have been arranged so as generally to place

together those of plutonics and the corresponding effusive rocks. The comparisons show the truth of Rosenbusch's statement that the effusives are, on the whole, somewhat higher in silica and alkalies and lower in iron oxides, lime, magnesia, etc., than the respective plutonics.

The importance of this rule is at least two-fold. It proves the value of Rosenbusch's primary division into the deep-seated types and the surface lavas. It shows therewith one of the reasons why the Norm [5] Classification of igneous rocks is largely a failure so far as either the field-geologist or the student of petrogeny is concerned.

Secondly, the rule suggests clearly that at volcanic vents there is a general cause for the removal of iron, magnesium, and calcium oxides from the magmatic columns and that the cause is more effective in volcanic vents than in the average plutonic body. The cause is most probably to be found in the gravitative settlement of part of the ferromagnesian and other constituents of early crystallization. These constituents may settle out either as solid crystals or as liquid fractions immiscible near the consolidation point of the magma. Since, on the average, the column of fluid magma is taller in an active volcanic vent than in a plutonic mass, the overlying phase of the splitting magma should be, in general, slightly more acid and alkaline than the corresponding pole of differentiation in a deep-seated mass. In the nature of the case the more acid-alkaline pole is the one most liable to flow out at the surface. Though volcanic vents are much narrower than plutonic chambers and therefore subject to quicker chilling, with a resulting check to differentiation, this tendency is largely counterbalanced by the passage of very hot gases through vents. The mere agitation in the vents facilitates the separation. Whatever additional considerations are necessary to complete the comparison, it must here suffice to note that, as a rule, the laws of solution as applied to magmas seem to demand a differentiation with slow cooling, whereby a surface lava is less basic and ferromagnesian than the plutonic body feeding the vent of that lava. The corroboration of Rosenbusch's above-mentioned rule through the world-averages appears, therefore, to be of use in illustrating one of the world-wide influences controlling the origin of igneous rocks.

Some special conclusions regarding classification may be noted. From the averages it is evident that dacite is the effusive correspondent of granodiorite and not of quartz diorite. The contention of

[5] Quantitative Classification of Igneous Rocks, by W. Cross, J. P. Iddings, L. V. Pirsson, and H. S. Washington, Chicago and London, 1903.

American geologists that the vast development of granodiorite in the Cordilleras of North and South America should alone give the name a primary place in rock classification, is again justified. The many occurrences of dacite throughout the world represent just so many additional masses of cooled magma which were chemically identical with, or closely related to granodiorite. In volumetric importance, as in mineralogical and chemical individuality, the granodiorite type should rank as of the same order as granite itself.

Quartz porphyry, liparite, and rhyolite show that essential identity of composition which has long been apparent from more qualitative comparison.

5. There is little noteworthy chemical difference between the average pre-Cambrian granite and the average granite of later periods. How far the differences in alumina and potash (columns **1**, **2**, and **3**) are due to the relative fewness of analyses of pre-Cambrian types cannot be stated. In spite of any such uncertainties the stability of the chemical type represented by granite throughout geological time is manifest. The explanation of the fact may well be found in Vogt's idea that granite is an "anchi-eutectic," a crystallized mother-liquor, a nearly extreme product of magmatic differentiation. It is possible that some of the older pre-Cambrian granite represents the differentiation of primeval magna. For many reasons it seems probable that most, if not all, post-Cambrian granites are differentiates from syntectic magma, chiefly composed of primary basaltic magma which has locally redissolved the ancient, acid shell overlying. In such case the splitting of the syntectic would ultimately give an acid differentiate similar to that formed in the primitive time. In general, differentiation in batholiths, when well advanced, restores the condition temporarily disturbed by magmatic assimilation. On this (confessedly hypothetical) view one may feel no surprise in noting a fairly steady composition in the granites from the average oldest type to the average youngest.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY,
BOSTON, January, 1910.